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Regulated Power Supply Design

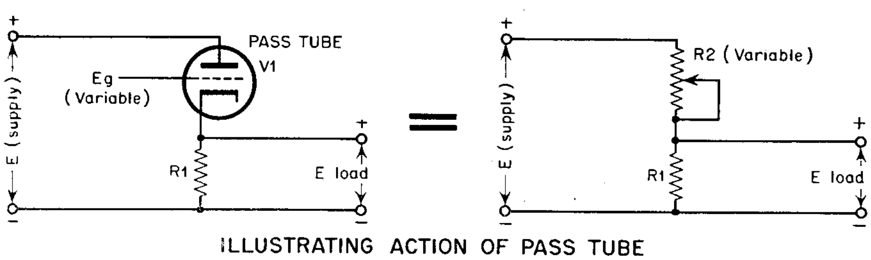
By the Engineering Department, Aerovox Corporation

A source of well-regulated plate voltage is a prerequisite for the modern laboratory, service bench or amateur station. An ever increasing number of electronic devices, such as audio amplifiers, r.f. oscillators, amaeur vfo's, oscilloscopes, synchroscopes, timing circuitry, and many others, depend for their proper functioning upon a power supply which is hum free and delivers a constant voltage regardless of load. Fortunately, the development of electronically regulated sources has advanced to the state where their design and construction is well within the scope of the average user. This article outlines the theory, design and construction of a representative supply of this type. With a firm understanding of the design principles to be discussed, the reader should be able to adapt the practical supply presented here to other requirements which might exist.

Modern regulated supplies of the type to be described make available an output voltage which is continuously variable over a considerable range and which will not vary more than a fraction of one percent between no-load and full-load conditions. Normal line voltage fluctuations also have little effect on output voltage. In addition, the regulation may be made of such a high order that ripple voltages in the output are almost entirely cancelled, thus eliminating the need for the usual "brute force" filter. This saving in weight and space helps to compensate for the additional complexity of the electronic regulator.

Theory of Operation

To achieve precise voltage regulation, an electronic voltage control element must be introduced in the conventional supply circuit. In most regulated supplies, this electronically variable element takes the form of a high current vacuum tube, usually called the "pass tube" or "regulator tube" in this application. This tube is connected in series with the load resistance across the output of the supply, as in Fig. 1. Since the resistance of the triode varies as a function of its grid voltage, this combination acts as an electronically controlled voltage divider. A small change in the regulator tube grid voltage changes the effective ratio of the divider and thus varies the voltage appearing across the output load.



ILLUSTRATING ACTION OF PASS TUBE
FIG. 1

The ability to vary the output voltage of the supply by a minute grid voltage change suggests that automatic voltage regulation could be accomplished by feeding any attempted output voltage fluctuation back to this grid at such a polarity as to oppose that change. In other words, if the voltage across the load in Fig. 1 attempted to rise, the grid of the pass tube (V1) should be made more negative so that its internal resistance would increase and lower the load voltage. If the load voltage attempted to decrease, the converse action should occur.

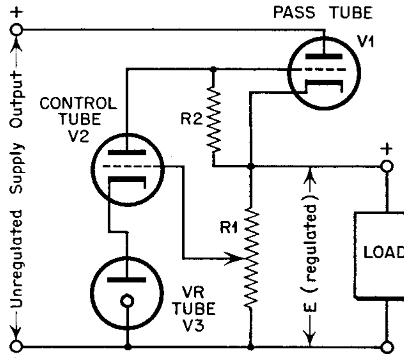
This action is achieved by the circuit shown in simplified form in Fig. 2. Auxiliary circuitry consisting of a second vacuum tube, usually called the "control tube", and a constant voltage source such as a battery or "VR" tube is added to the circuit of Fig. 1. A sample of the output voltage is applied to the grid of the control tube by a tap on the output bleeder R1. The control tube determines the bias on the regulator tube (V1) since the load resistor (R2) for the control tube is also the bias resistor for the regulator tube. The control tube therefore performs two functions; it amplifies voltage fluctuations impressed upon its grid by the output circuit, and it reverses the phase of those fluctuations so that they may be applied to the grid of the pass tube in the right direction to effect regulation. The precision of the regulation attained increases with the gain of the control tube since, with greater gain, a small change in control tube grid voltage will cause a greater control tube current change and hence a greater change in pass tube bias. Thus, smaller attempted output voltage excursions will be corrected.

The battery or VR tube maintains the cathode of the control tube at a constant voltage above ground, and thus provides a standard reference voltage to which voltage fluctuations at the output divider (R1) are compared. The voltage at the grid of the control tube is the difference between the voltage at the output bleeder tap and the reference bias voltage provided by the VR tube. This difference voltage sets the "target" voltage to which the supply regulates. By changing the output bleeder tap with a potentiometer at R1, the regulated output voltage of the supply may be adjusted within certain limits.

Summarized briefly, the action of the electronic regulator of Fig. 2 is as follows: The position of the bleeder tap on R1 determines the output voltage level to which the supply will regulate. If the voltage across the bleeder attempts to rise above that level, the bias on the control tube (V2) becomes more positive, causing it to draw more current through its load resistor (R2). The increased current through R2 causes the grid of the regulator tube (V1) to be driven more negative, with the result that the resistance of the regulator tube increases sufficiently to prevent the original attempted excursion of output voltage and return it to the regulated level. If the output voltage attempts to *decrease*, the sequence of events is exactly opposite. The action is practically instantaneous, so that excursions are corrected for while still very small.

Practical Design Considerations

With a working knowledge of the functions of all component parts, the design of regulated power supply equipment is no more complicated than that of other electronic circuitry usually designed and constructed by the user.



SIMPLIFIED
ELECTRONIC REGULATOR
FIG. 2

As with any power supply design, the first step is to determine the desired output voltage and current requirements. This permits the selection of the proper power transformer, filter components, and pass tube. The supply section differs from standard design only in that considerably more voltage than the required output voltage must be provided since there is an appreciable minimum voltage drop across the regulator tube. Usually the unregulated section of the supply must furnish from 50 to 200 volts more than the desired regulated output.

For a sample design, let us suppose that a regulated output of about 300 volts at 75 milliamperes is required for a general utility supply. The practical circuit for such a supply is shown in Fig. 3. Knowing the current requirement, a suitable pass tube may be selected from Table I. Any triode or triode-connected pentode capable of passing the required current at a reasonable voltage drop may be employed. Tubes may readily be used in parallel where greater current is required or when greater plate dissipation is needed. Special types, such as the 6AS7 which was designed for pass tube applications, are also available. For our present design, a smaller tube such as the 2A3 or its 6.3 volt equivalent, the 6A3, will suffice.

TABLE I

TUBE TYPE	CURRENT (Ma.)
6AS7G	250
6A3	75
2A3	75
6B4G	75
6A5G	75
807 *	80
6L6 *	75
6V6 *	45
6F6 *	40
6Y6 *	60

* Screen connected to plate through 500 Ohm, 1 Watt resistor

The power transformer and filter choke must be *conservatively* rated for the full load current. Otherwise, the regulation of the supply will be poor. The required voltage rating for the transformer is determined by finding the sum of the voltage drops around the circuit for the condition of maximum output voltage and current. The drop across the pass tube is minimum for maximum output voltage and may be found by referring to the plate characteristic curves for the pass tube being used. For the 6A3 used in the present design, the minimum tube drop for the required load current is about 80 volts at zero bias. Actually, somewhat greater values should be designed for to provide a margin for low line voltage conditions. For the 6A3, a minimum drop of 140 volts is typical. Thus, the d.c. output of the supply section ahead of the regulator must be about 440 volts; 300 volts for the load and 140 minimum drop across the pass tube. Reference to the rectifier tube operating characteristics will indicate the r.m.s. voltage rating of the power transformer required to supply this voltage when a single section choke-input filter is used. With the 5U4-G employed in the present design, and allowing sufficient margin for voltage drop across the choke, low line voltage, etc., a transformer delivering 550 volts each side of center-tap at 100 ma. is indicated. The choke should also be rated at 100 ma.

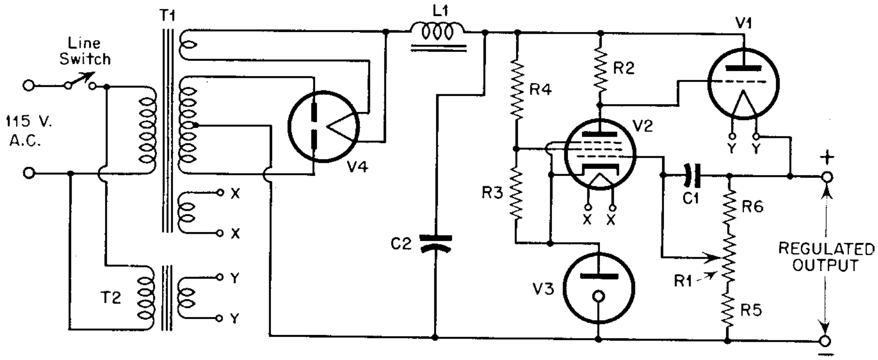
At this point, having selected the pass tube and determined the characteristics of the unregulated supply section, it is well to examine the pass tube operating conditions to determine if the allowable plate dissipation is being exceeded. The 6A3 is rated at 15 watts maximum dissipation. At full current and voltage from the supply, the drop across the pass tube estimated above was 140 volts. The plate dissipation under this condition is 140v. times .075 amps. or 10.5 watts. The low voltage limit to which the supply can safely be adjusted at full current may now be determined, since the voltage drop across the pass tube, and hence its plate dissipation, is maximum at the lowest regulated output voltage. The allowable drop for 15 watts plate dissipation is now calculated as 15 watts, .075 amp. or 200 volts. With a total unregulated voltage of 440v. available, the minimum regulated output of the supply is thus 240 volts. By using a larger pass tube, or several in parallel, the range of regulated voltage adjustment can be appreciably extended.

The choice of a control tube is rather arbitrary. Almost any pentode having a sharp cut-off characteristic may be used. The type most frequently employed in electronically regulated supplies is the 6SJ7, which is chosen for its low cost, ready availability, and high gain. Miniature types having similar characteristics may be used in applications where space is at a premium. The 6SJ7 will do nicely for the design under consideration.

Although batteries may be used for the source of control tube reference bias voltage, the gaseous voltage regulator tube is usually preferred. Tubes of the "VR" series give excellent life and stabilization in this application. The choice of VR type, VR75, 90, 105 or 150, depends on the unregulated voltage available and the portion of this which must be reserved for drop across the load-bias resistor (R2) and the control tube. It is desirable to utilize the highest voltage VR tube possible under these conditions, since this subjects the grid of the control tube to a larger portion of output voltage fluctuations. A VR150 is sufficient for the design being discussed, since the bias developed across R2 to reduce the output voltage to minimum is only about -30 volts, as indicated by the plate curves for the 6A3. The plate load resistor (R2) is chosen to be about equal to the plate resistance of the control tube. Values between .47 and .68 megohm are typical for the 6SJ7.

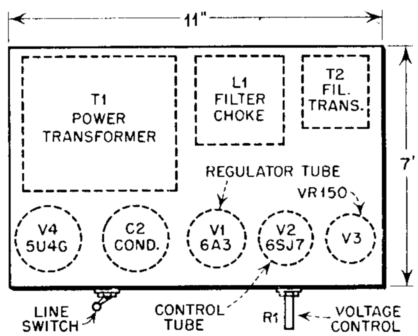
The by-pass capacitor, C1, is usually about .25 microfarads. It provides a path for 120 cycle ripple voltages and other high frequency fluctuations between the regulated output and the grid of the control tube.

The dropping resistors R3 and R4 are designed to provide 150 volts across the VR tube at the 8 ma. minimum current required for regulation and to provide a tap for control tube screen voltage. In computing the values of these resistors, the minimum unregulated supply output voltage must be used. Allowing for 10% drop in line voltage, this would be 396 volts in the present case. The required drop is then 396 minus 150 or 246 volts. At .008 ampere drain, the total resistance required (R3 and R4) is 246/.008 or 30,750 ohms. The portion of this resistance between the cathode and screen of the control tube to furnish a screen voltage of 100 volts should be 100/.008 or



R1, R5, R6 – See text
R2 – .47 Megohm, 1 Watt
R3 – 12,000 Ohms, 5 Watt
R4 – 18,000 " "
L1 – Filter choke, 8 Hy., 100 Ma.
C1 – .25 μfd, Aerovox Type 84
C2 – 8 μfd, Electrolytic, Aerovox Type GL-EP
T1 – Power Transf., 550-0-550 V. @ 100 Ma. 5 V. @ 3 A. and 6.3 V. @ 1 A.
T2 – Filament Transf., 6.3 V. @ 1 A.
V1 – 6A3
V2 – 6SJ7
V3 – VR150
V4 – 5U4G

PRACTICAL REGULATED SUPPLY
FIG. 3



SUGGESTED PARTS LAYOUT FOR REGULATED SUPPLY
FIG. 4

12,500 ohms. Thus the nearest standard values of 12,000 and 18,000 ohms will suffice for R3 and R4 respectively.

The total resistance value for the output bleeder is usually about .25 megohm, made up of a 50,000 wire-wound potentiometer for the voltage output adjustment and fixed carbon resistors (R5 and R6) above and below it to complete the total. The exact values of these for any particular regulated supply are most easily determined experimentally by substituting a .25 megohm potentiometer temporarily in place of R1, R5 and R6. Then, with the supply operating, the settings of the potentiometer tap for the minimum and maximum outpu tvoltages allowable under full load conditions can be determined. The potentiometer is then disconnected and the resistances measured with an ohmmeter. The resistance between the slider position for low voltage output and the ground end of the "pot" is the value for R5. Similarly, the resistance measured between the slider setting for high output voltage and the "hot" end of the potentiometer is the value for R6. The correct value for R1 is then R5 plus R6 subtracted from .25 megohm.

Construction

Standard power supply wiring practices apply to all portions of the regulated supply except the control tube section. Since this tube is acting as a high gain d.c. amplifier, it is very susceptable to hum pick-up which will appear as ripple in the output voltage. To minimize this, all leads associated with the control tube, and especially the grid lead from R1, must be as short as possible. The best practice is to mount the voltage control potentiometer adjacent to the control tube socket at a location as far as possible from the power transformer, filter chokes, filament transformers, and other components which produce hum fields.

A chassis lay-out which is suitable for the design discussed above is shown in Fig. 4. All parts are mounted on a 7 x 11 x 2 inch metal chassis. Well-shielded components should be used and all a.c. leads must be twisted in pairs to reduce hum radiation. A separate filament winding is required for the regulator tube since the filament of this tube is operated at the full supply output voltage above ground. When the special 6AS7G pass tube is used, this precaution is not necessary because the heater-cathode insulation in this tube is sufficient to withstand 300 volts.

The completed supply should be checked for satisfactory regulation by varying the load current from the full design rating to zero. Under these conditions, the change in output voltage should be negligible. Ripple content can be checked qualitatively with earphones coupled through a suitable condenser, although an oscilloscope is very much preferable.

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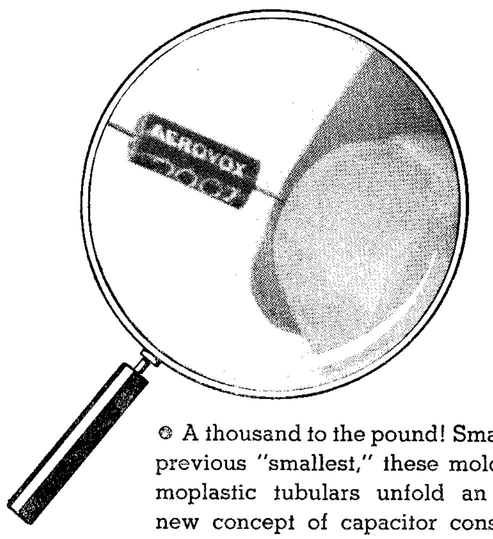

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